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DESIGNING HIGH RESOLUTION COUNTRYWIDE DEM FOR TURKEY

Yılmaz, A., [1]* Erdogan, M.,[2]

[1]General Command of Mapping of Turkey, Photogrammetry Department, Ankara, Turkey
(altan.yilmaz@hgk.msb.gov.tr);

[2]General Command of Mapping of Turkey, Photogrammetry Department, Ankara, Turkey
(mustafa.erdogan@hgk.msb.gov.tr)

ORCID ID 0000– 0002– 1926– 0633; ORCID ID 0000-0003-3219-5546

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*Corresponding Author, Received: 27/01/2018, Accepted: 12/04/2018

ABSTRACT: Digital Elevation Models (DEM) are widely used in many different applications such as orthophoto production, 3D city models, hydrological modeling, visibility, flood, flood analysis and etc. The densest grid spacing DEM covering Turkey is the DTED-2 data produced by the General Command of Mapping with a grid spacing of 1 second (approximately 30 m). Denser and more accurate DEM is produced by several institutions in only required areas but not covering whole country. Governmental institutions need denser, more accurate, homogeneous and countrywide DEM. This study is conducted to meet DEM demands with optimum accuracy and density by stereo aerial photos. In order to investigate the optimal resolution for a countrywide DEM, test DEMs are produced in three different areas representing the general topographic structure of Turkey by using 45 cm ground sampling distance stereo aerial photos. The Root Mean Square Error (RMSE) of the heights of three areas are respectively ± 2.51 m, ± 1.38 m and ± 1.30 m. The proposed grid spacing by INSPIRE with these accuracies is 3-30 m in flat terrain and 3-15 m in mountainous terrain. It is concluded that 5 m grid spacing will be suitable for a countrywide DEM with the above mentioned accuracies. It is also proposed that production format of DEM should be 32 Bit Floating GeoTiff.

Keywords: *Digital Elevation Model, aerial photos, automatic image matching, countrywide DEM*

1. INTRODUCTION

Terrain surface elevations are the most commonly used geographic information. These data are distributed as Digital Elevation Model (DEM) and their derivatives are used in a wide range of applications such as orthophoto production, 3D city models, hydrological modeling, visibility and flood analysis (Fisher et al., 2006).

Grid structure is the most common geographic data model used in modeling terrain and underwater heights. Grids are represented by a set of regular or evenly distributed points. Because the altitudes are at regular intervals, only an elevation value is stored on a horizontal coordinate. By taking advantage of this point, the horizontal position of the other points can be determined together with the reference coordinate information. Grid is also an easy structure for data processing. The grid spacing can be chosen to be most effective according to the size and the density of the land surface to be modeled (Federal Geographic Data Committee, 2008).

DEMs are divided into two according to the topographic features they represent. Digital Surface Model (DSM) refers to DEM which covers human made structure and vegetation cover. Digital Terrain Model (DTM) refers to the remaining surface of the bare earth when the above mentioned details are omitted (Figure 1) (Höhle, 2009).

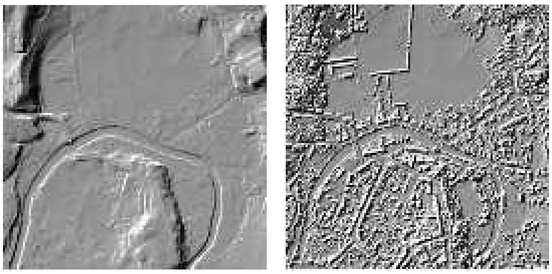

Figure 1. DSM (on the left) and DTM (on the right)

DEM is the product of a series of modeling and processing steps. DEM can be obtained from sources such as terrestrial measurements, contours, vector data, aerial photos and satellite images, aerial and space radar data (synthetic aperture) and laser scanning (LIDAR). DEM contains mistakes due to the source and method of production. The fact that these errors are known in DEM is also important in terms of identifying the mistakes caused by the use of DEM in various applications.

Fisher et.al., (2006) put forward three main error sources for DEM: one from the source data including accuracy, density and distribution; the other from production method the DEM from the source; and lastly from the topography of the terrain being modelled.

Höhle (2009) found ±13 cm standard deviation vertical accuracy for the DEM produced from different digital aerial cameras with 60% overlap and 6 cm Ground Sampling Distance (GSD) aerial photos. He related the known elevation error formula with the image matching accuracy which is also a function of photogrammetric software system and the GSD of the aerial photos used.

Pulighe et al., (2013) used 1:34,000 scale analog aerial photos scanned at 1200 dpi resolution (which means 0.70 cm GSD) for DEM production. He produced 5 m grid spacing DEM autocorrelation and obtained ±4.90 m Root Mean Square Error (RMSE) at checkpoints.

In Turkey; the first DEM productions were carried out in the 1980’s by General Command of Mapping (GCM). These DEMs were produced with a spacing of 15 "x 20" by reading the elevation values from hardcopy maps. In 1989, the contours were digitized from hardcopy maps. This product, called YÜKPAF, is a vector created by transferring the sea, lake and wide bed creeks, altitude and landmark points in the topographic maps to the computer environment together with altitudes from sea level. Two different resolution DEMs were produced: one from 10 m spacing contours for 1: 25.000 scale (YUIKPAF 25) and the other from 100 m spacing contours for 1: 250.000 scale (YUKPAF250). Production of 1:25.000 scale YUKPAF was carried out between 1989 and 1999, 1:50.000 scale YUKPAF production was carried out between 1994 and 2005, and 1:250.000 scale YUKPAF production was carried out between 1992 and 2001.

Production of first level DTED (Digital Terrain Elevation Data) which can be used in various weapons systems, engineering services, field applications and simulators with a 3 second interval, second level DTED production with 1 second intervals and second version of second level DTED production were completed in 1994, 1998 and 2001 respectively from YUKPAF. DTED is a land height value in the form of a uniform matrix that is developed by the National Geospatial-Intelligence Agency of USA (NGA) to support military applications, providing basic data on systems or applications that require information such as land height, slope and/or surface roughness. DTED Level 0; 30 arc-seconds spacing (nominal 1 km), DTED Level 1; 3 arc-seconds spacing (nominal 100 m) and DTED Level 2; 1 arc-arc spacing (nominal 30 m) height data (NATO STANAG MIL-PDF-89020B). In the production of DTED, topographic map data was used first and then Space Shuttle RADAR Topography Mission (SRTM) was used. Other remote sensing techniques, aerial photos, field survey and LIDAR systems can also be used to generate DTED data. The accuracy criteria for DTED-2 in NATO STANAG MIL-PDF-89020B are 23 m horizontally and 18 m vertically.

The accuracy of DTED-2 and SRTM-1 are investigated in a study conducted on İzmir Region. They are compared with accurate 308 geodetic control points. It is found that DTED-2 has ± 3.85 m RMSE and SRTM1 has ± 4.45 m RMSE (Fırat et al., 2015).

Over time, DTED-2 has not been able to meet the high accuracy and resolution DEM requirements of users. General Command of Mapping which is the responsible institution for countrywide mapping for middle and small scales mapping for Turkey, has begun to investigate how to produce digital elevation models in the most appropriate accuracy and grid spacing to meet the user needs. In order to find a medium to resolve the accuracy and grid spacing, digital surface and terrain models were produced with dense image matching in three different regions. The accuracy of DTED-2 and SRTM-1 data for the same regions were also investigated and optimal resolution was suggested within the scope of INSPIRE criteria according to the accuracy of automatically generated DEM.

The aim of this paper is not to make an accuracy assessment of DEM produced from stereo digital aerial photos, but to investigate the optimal resolution for a countrywide DEM regarding the accuracy of automatically generated DEM. In the following sections, the countrywide DEM production of different countries is analyzed at the beginning; then the accuracy and optimal grid spacing of DEM produced in three different areas are investigated; lastly some conclusions are drawn.

2. COUNTRYWIDE DEM PRODUCTION APPLICATIONS IN DIFFERENT COUNTRIES

The German Federal Cartography and Geodesy Agency (BKG) has introduced digital elevation models across the country between 1: 50.000 and 1: 1.000.000 scales and approx. ± 20 m vertical accuracy by 2003, while the federal states in the same period have digital elevation models between 1: 5.000 and 1: 50.000 scales and with ± 0.3 m and ± 5 m accuracy. However, there was no national high-precision digital elevation model. For this purpose, firstly a digital elevation model was produced with accuracy between ± 1 m and ± 3 m on 1:25.000 map scale. Subsequently, BKG had to combine digital elevation models produced at different intervals, in different coordinate systems, with different accuracies and with different production methods (laser scanning, photogrammetry, digitization of analogue maps), and quality controls were carried out with GNSS measurements in the relevant areas (Hovenbitzer, 2004). The BKG now presents elevation models at 10 m, 25 m, 50 m, 200 m and 1.000 m grid intervals. From these data, 200 m and 1.000 m grid spacing DEMS were produced from contours obtained from 1: 500.000 scaled maps; those with 10 m, 25 m and 50 m grid spacing were obtained from laser scanning, photogrammetric methods and contours. The elevation accuracy of the 10 m grid spacing digital elevation model is between ± 0.5 m and ± 2 m (Bundesamt für Kartographie und Geodäsie (BKG), 2012).

The Canadian Topographic Information Center (CTI) produces the Canadian Digital Elevation Database (CDED) jointly with federal and regional government agencies and the private sector. The data is presented as Geobase Level 1, which is represented between 1:10,000 and 1:250.000 average scales in resolutions according to the region. The main source for CDED is the hypsographic and hydrographic data of the National Topographic Database. The grid spacing for the 1: 50,000 scale CDED is 0.75 arc-seconds in the north-south direction (approximately 23 m). In the west-east direction, it ranges from 0.75-3 arc-sec (about 16-11 m). The accuracy of the data is less than ±5 m in vertical, depending on the production method and area. CDED is presented in a grid of 1201 rows and columns (Canada Center for Topographic Information, 2007).

The National Elevation Data Framework (NEDF) has been established in Australia to provide easier access to existing elevation data and to provide the most appropriate solution for collecting new data. The project started with the aim that use of the data from all sources with the highest resolution available and find out the need for the digital elevation model in all public levels. The first review of the data was made in 2008. The data consists of digital elevation models from the SRTM with 1 and 3 second intervals covering the entire continent, and digital elevation model with 9 second intervals, and also increasing high resolution elevation data available in residential areas and open coastal areas in danger (Geoscience Australia, 2011).

The National Elevation Dataset (NED) is the base elevation data generated and distributed by the U.S. Geological Survey (USGS). The NED provides uninterrupted grid elevation data in the United States, Alaska, Hawaii, and the islands. NED consists of data produced from different sources according to a specified resolution, coordinate system, and elevation unit, horizontal and vertical datum. The production steps of the data are shown in Figure 2 (Gesch et al., 2002).

The NED data is presented at grid intervals of 1 arc-second seamlessly for the entire United States, and at 1/3 and 1/9 arc-bases intervals for some parts of the United States. There is also a layer of metadata that can be accessed via web as a separate layer with elevation data, such as data source, production style, coordinate system, horizontal and vertical datum, and elevation unit. NED data accuracy is tested by geodetic control points used by the US National Geodetic Survey Unit in gravity and geoid modeling studies. In 2003, it was determined that the accuracy of the whole data was ±3.99 m absolute vertical accuracy at the 90% confidence interval carried out with 13.305 point. The NED is provided through a web service and the users can download the data using an interface. Data covering very large areas are provided to the user via external storage units (U.S. Geological Survey (Gesch et al., 2002).

To support a splendid knowledge about the vertical accuracy of the NED, 2013 version of the dataset was tested with 25,000 survey points in centimeter level accuracy. It was found that RMSE of ±1.5 m vertical accuracy at 95th percentile. Also NED was compared with other large area elevation datasets, i.e. SRTM data and ASTER Global Digital Elevation Model (GDEM). The NED was proved to be more accurate than SRTM and ASTER GDEM with a RMSE of 4.01 meters for SRTM and 8.68 meters for ASTER GDEM in spite of RMSE of 1.84 meters for the NED (Gesch et al., 2014).

Several studies are carried out about the accuracy of SRTM-1 and ASTER GDEM. Bildirici et al., (2017) compared SRTM and ASTER GDEM with the DEM produced from 1:25K Turkish standard topographic maps. They found that SRTM-1 gives better accuracies according to ASTER GDEM on test areas. Bildirici et al., (2013) also tested SRTM-3 accuracy over Turkey and found that SRTM-3 is about 13 m in accordance with 1:25K national DEM.

Yue et al. (2017) combined SRTM-1, ASTER GDEM and ICESat DEM in order to produce a more accurate void filled data over China. The results show that combined dataset has a better data quality compared with the original dataset.

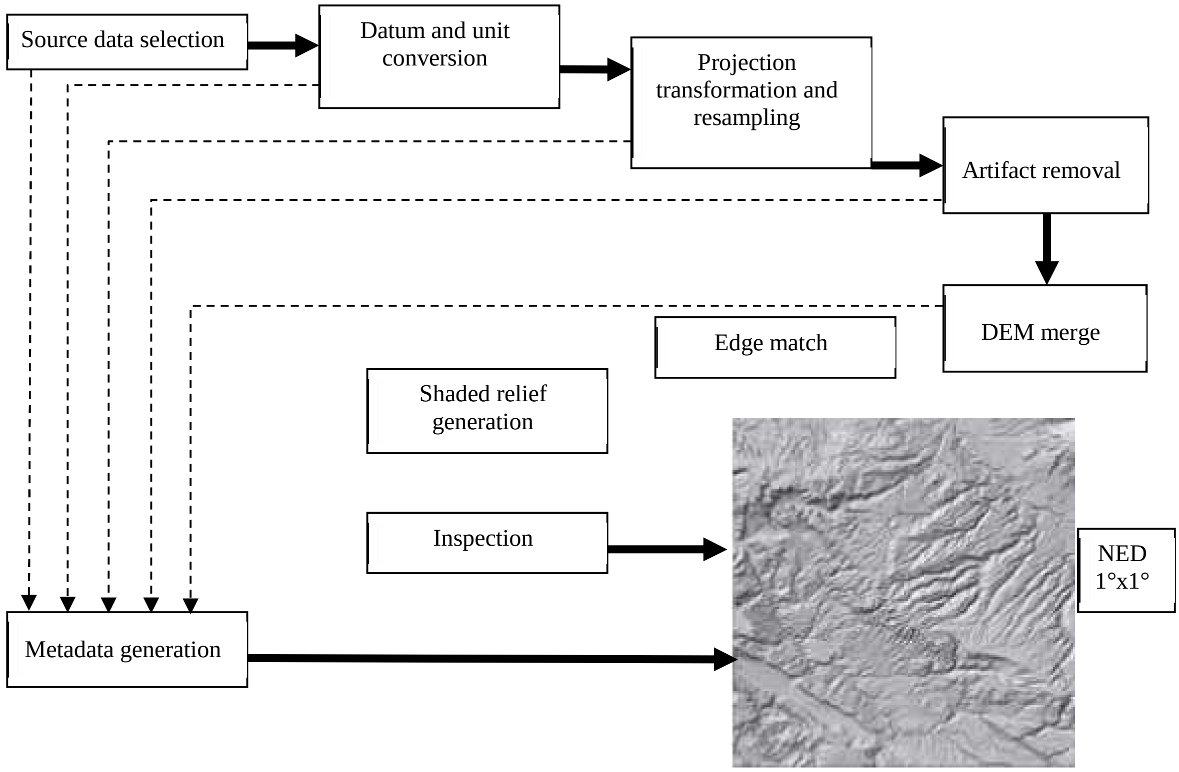

Figure 2. NED production workflow (Gesch et al., 2002)

3. HIGH RESOLUTION DEM PRODUCTION ANALYSIS

With the introduction of digital aerial cameras, the radiometric and spatial resolutions of the images have increased, and automatic matching algorithms of the software have been developed. In particular, dense image matching (Haala, 2012) or semi-global matching (Hirschmüller, 2011) algorithms provide a significant improvement in the accuracy of automatically generated DEMs. Depending on these developments, DEM can be produced almost automatically on a pixel-by-pixel basis.

It was in 2008 that first digital aerial camera was being used for aerial photo acquisition by GCM. The aerial photo acquisition began with capturing 45 cm GSD photos, but then the GSD has increased to 30 cm regarding the countrywide high resolution image requirements. Although there are more high resolution aerial photo requirements for residential areas 10 to 5 cm GSD, countrywide mapping goes on 30 cm GSD aerial photo acquisition nearly in every three years for Turkey. The aerial photos are mainly used for topographic map updating, orthophoto and DEM production. In order to meet the growing needs for a high resolution DEM, 30 cm GSD aerial photos are determined as source data.

In order to analyze the existing elevation data, 20 Ground Control Points (GCP) marked on the ground and determined the position with GNSS at ±7 cm positioning accuracy in elevation and 76 stereo Check Points (CP) read from aerial photo stereo models at identifiable points in Ankara region. DTED-2, SRTM-1 and 5 m resolution DEM produced from stereo aerial photos with autocorrelation (DEM5m) are the test datasets for this region. The elevation of GCPs and CPs are compared with the elevations of DTED-2, SRTM-1 and DEM5m. Vertical datum is EGM96 for SRTM-1 and TUDKA-99 (Turkish National Vertical Control Network) for other datasets. Since the datum difference between EGM96 and TUDKA-99 is about 0.5 m, it is neglected in the calculations (Tepeköylü et al., 2008). This difference decreases to nearly 30 cm for EGM2008 (Yilmaz et al, 2016). The mean difference, standard deviation (σ) at 68% and 90% Confidence Interval (C.I.) are given in Table 1. When Table 1 is examined, it is clear that DEM5m is superior to other DEM products even without editing.

Table 1. Accuracy assessment of existing DEMs

Source	# and Type of Control Points	Mean Diff. (m)	σ (± m) (% 68 C.I.)	σ (± m) (% 90 C.I.)
DTED-2	20 GCP	-0.73	3.21	5.28
	76 CP	-1.45	4.79	8.23
SRTM-1	20 GCP	1.23	2.29	4.27
	76 CP	1.72	2.65	5.21
DEM5m	20 GCP	-0.24	1.7	2.83
	79 CP	0.16	2.47	4.27

In order to test the accuracy of DEM5m, three test areas, which are Uşak L23-b3, Aksaray L30-a1 and Doğubayazıt J51-a1 are selected to represent the different types of topography over Turkey.

3.1. The Accuracy Assessment in 1:25,000 Scale UŞAK L23-b3 Map Sheet

UŞAK L23-b3 consists of medium density residential and wooded area (1/3 of the map sheet is dense forest); it reflects Turkey's topography with overall height differences (800 m - 2800 m); it contains flat and undulating terrain (Figure 3).

Figure 3. L23-b3 DEM (left) and orthoimage (right)

8,000 3D control points are precisely read from stereo models for accuracy assessment of the DEM. These 3D control points are evenly distributed to the test area representing all different characteristics of the topography. The accuracy of the stereo models after standard photogrammetric triangulation is ± 0.5 m in horizontal and ± 0.75 m. in vertical.

The streams from the photogrammetric compilation and breakelines have been used for the production of point cloud for the DEM. Also, other the parts of the terrain where the elevation changes abruptly are compiled as vectors and incorporated into the point cloud.

First, the existing DTED-2 and SRTM-1 data of the study area were investigated with 3D control points and the results were given in Table 2. During the photogrammetric revision made in this map sheet, contours were also improved. A DTM was generated from the improved contours and other vector data (creek, lake, etc.) which may contribute to the height. The accuracy of the vector DTM was also included in Table 2. After comparing the accuracy of the DTM generated from the improved contours with the existing DTED-2 data, the improved contours provides an improvement of about 2 meters in DTM accuracy.

Table 2. L23-b3 DTED-2, SRTM-1 and Vector DTM accuracy assessment

Data	#of points over 3σ (22 m)	Mean Error (m)	RMSE (± m) (68% C.I.)	Accuracy (± m) (90% C.I.)
DTED-2	109	-1.04	7.19	11.95
SRTM-1	152	-1.81	6.55	11.18
Vector DTM	107	-0.39	5.74	9.47

Note: C.I.: Confidence Interval.

For the production of DTM with higher accuracy and resolution, the existing stereo aerial photos were used for automatic DTM production with 5 m grid spacing; streams, creeks and breakelines were used as ancillary data. Inpho Match-T software is used in automatic DTM production.

After the DTM point cloud produced in Inpho MatchT software is controlled on stereo aerial photos in DTMaster Stereo software it is inferred that;

- DTM produced in bare surface areas represents the topography very well,
- In the wooded and forested areas, it represents the topography as surface but passes over the forest and wooded areas,
- Mistaken points can be automatically eliminated,
- It is important that the inclusion of breakelines (streams, creeks etc.) in DTM production is essential for the contour production (Figure 4),

Figure 4. Contours produced with streams included

- The inclusion of ridge lines is not appropriate as breakelines because the system sharpens the ridge slope in these regions and this data should be included as softlines (Figure 5),

Figure 5. Ridge lines and produced contours

- It is necessary to pre-draw lines perpendicular to the ridge lines in order to include the bare ground in the wooded areas,
- Extremely wide wooded areas can be corrected with operator intervention simply by the Stereo Editing software (Figure 6),
- The editing made with the Stereo Editing software are the result of the new situation reflecting the "on the fly"
- If the tree dimensions are close to each other in the forest areas, the height of the selected area can be

lowered to the ground,

- Since the tree sizes usually differ in the forested areas, it is necessary to make corrections by drawing the lines of the breakelines in the places where the ground can be seen in the Stereo Editing software.

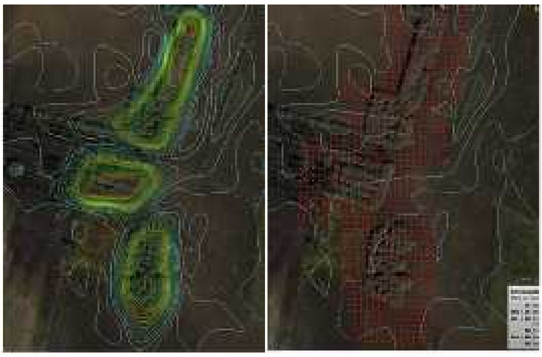

Figure 6. Mistaken point cloud for trees (left) and corrected point cloud for DTM (right)

The above ground points in the automatically generated DTM, such as buildings, trees and etc., were dropped down to the bare ground in stereo editing software either by using additional vector data on the ground or automatic correction tools of the software. Then 5 m, 10 m, 15 m and 20 m grid spacing DTMs were obtained and compared with 8,000 control points. The result of the accuracy assessment is presented in Table 3. When Table 3 is examined, it is seen that the grid spacing of 5 m or 10 m does not significantly affect the accuracy. It is seen that increasing the interval to 20 meters decreases both the accuracy and the number of points passing 3σ.

Table 3. L23-b3 accuracy assessment of different grid spacing for edited DTMs.

Grid Spacing (m)	# of points over 3σ (22 m)	Mean Error (m)	RMSE (± m) (68% C.I.)	Accuracy (± m) (90% C.I.)
5	341	-0.17	1.52	2.51
10	362	-0.13	1.59	2.62
15	554	-0.01	1.66	2.72
20	637	0.05	1.86	3.07

The 32 bit GeoTIFFfile sizes of 5 m and 10 m spacing are 25 MB and 6 MB respectively.

According to USA "Geospatial Positioning Accuracy Standards - FGDC-STD-007.3-1998"; the coefficient of 1.6449 is applied in the 90% confidence interval for the height accuracy that fits to the normal distribution.

$VMAS=1.6449 \times RMSE_Z$ (VMAS = Vertical Map Accuracy Standard)

$AccuracyZ=1.9600/1.6449 \times VMAS=1.1916 \times VMAS$

$VMAS = 1.6449 \times 1.52 = 2.50$ m

$AccuracyZ = 1.1916 \times 2.50 = 2.98$ m (95% Confidence Interval)

INSPIRE sets forth the formula given in Table 4 for determining grid spacing for elevation data.

Table 4. INSPIRE grid spacing standards

Proposed Grid Spacing	Ground Type
$3xRMSE_z \leq$ Grid Spacing $\leq 20xRMSE_z$	Flat and undulating terrain
$3xRMSE_z \leq$ Grid Spacing$\leq 10xRMSE_z$	Hilly and mountainous terrain

The recommended grid spacing according to the $RMSE_Z$ ($RMSE_Z \approx 1.6$ m) is calculated and given in Table 5.

Table 5. DTM grid spacing calculation

Proposed Grid Spacing	Ground Type
4.8 m ≤ Grid Spacing ≤ 32 m	Flat and undulating terrain
4.8 m ≤ Grid Spacing≤ 16 m	Hilly and mountainous terrain

When examining the grid spacing standards recommended by INSPIRE, one of the grid spacing of 5 m and 10 m for DTM would be appropriate to accurately reflect the characteristics of the topography from the digital stereo aerial photos and to be of sufficient accuracy.

The editing of the produced DTM (in a medium difficulty level) at an acceptable level takes 5 days, and additionally the editing of the contours takes 3 days. It is estimated that the correction of DTM of a 1:25.000 scale map sheet area completely covered with forest or dense buildup can last at least 10 days.

3.2.The Accuracy Assessment in 1:25,000 Scale Aksaray L30-a1 Map Sheet

The L30-a1 map sheet was chosen to reflect the little differences in altitude, high vegetation cover and settlement site density. The altitudes vary from 920 to 1008 meters (Figure 7). The map is located in the south west of the Salt Lake. It contains mostly flat terrain.

250 three-dimensional control points from stereo models are read precisely for the accuracy assessment of DEMs. The horizontal accuracy that can be obtained from the stereo models after standard photogrammetric triangulation applied to the used photos is ±0.5 m and the vertical accuracy is ±1.0 m.

First, the existing DTED-2 and SRTM-1 data of the study area were tested with three-dimensional coordinates read through the stereo models and the results are given in Table 6.

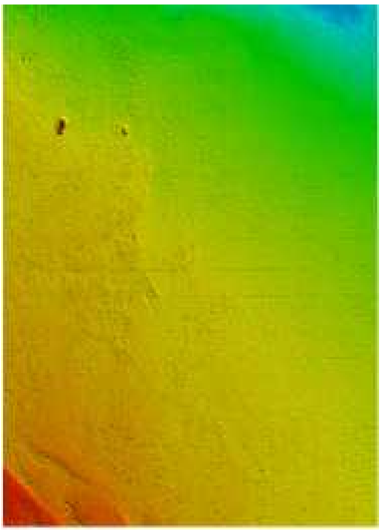

Figure 7. L30-a1 Digital Surface Model

Table 6. L30-a1 DTED-2 and SRTM-1 accuracy assessment

Data	#of points over 3σ (22 m)	Mean Error (m)	RMSE (± m) (68% C.I.)	Accuracy (± m) (90% C.I.)
DTED-2	2	-1.19	1.86	3.63
SRTM-1	0	1.26	1.25	2.93

Point cloud was collected as DTM using Inpho Match-T software in L30-a1 map sheet area and the automatically unfiltered terrain details were edited in stereo editing software. Resulting DTM was sampled as 5 m, 10 m, 15 m and 20 m in 32 bit Geotiff and accuracy assessment was carried out. The results obtained from the accuracy assessment are given in Table 7. When Table 7 is examined, there is no difference in accuracy levels between 5 m and 20 m grid spacing due to the fact that the land is very flat.

Table 7. L30-a1 accuracy assessment of different grid spacing for edited DTMs

Grid Spacing (m)	# of points over 3σ (22 m)	Mean Error (m)	RMSE (± m) (68% C.I.)	Accuracy (± m) (90% C.I.)
5	0	-0.71	0.45	1.38
10	2	-0.69	0.43	1.33
15	2	-0.69	0.43	1.34
20	1	-0.69	0.44	1.33

The total production of L30-a1 map sheet from DSM to DTM and DTM to contours lasted for two days, including editing works. The automatic production of contours (Figure 8) is not directly suitable due to terrain flatness. An operator intervention is required to edit the automatically produced contours in order to properly represent the topography with a cartographic sense.

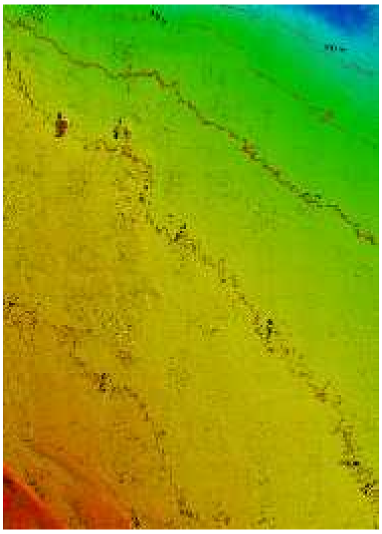

Figure 8. L30-a1 automatic contour production

3.3. The Accuracy Assessment in 1:25,000 Scale Doğubayazıt J51-a1 Map Sheet

J51-a1 map sheet is chosen for it represents the great height differences and deep valleys, high vegetation cover, and areas where the density of settlement is low. Heights in the field vary between 1930 and 3300 m (Figure 9). It contains hilly and mountainous terrain. The area is located in the north east of Van Lake.

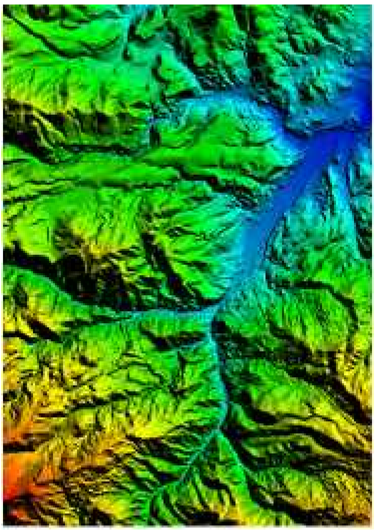

Figure 9. J51-a1 Digital Surface Model

124 three-dimensional control points from stereo models are read precisely for the accuracy assessment of DEMs. The horizontal accuracy that can be obtained from the stereo models after standard photogrammetric triangulation applied to the used photos is ±0.5 m and the vertical accuracy is ±1.5 m.

First, the existing DTED-2 and SRTM-1 data of the study area were tested with three-dimensional coordinates read through the stereo models and the results are given in Table 8.

Table 8. J51-a1 DTED-2 and SRTM-1 accuracy assessment

Data	#of points over 3σ (22 m)	Mean Error (m)	RMSE (± m) (68% C.I.)	Accuracy (± m) (90% C.I.)
DTED-2	3	-2.19	4.36	8.03
SRTM-1	2	1.20	4.84	8.20

Point cloud was collected as DTM using Inpho Match-T software in J51-a1 map sheet area and the automatically unfiltered terrain details were edited in stereo editing software. Resulting DTM was sampled as 5 m, 10 m, 15 m and 20 m in 32 bit Geotiff and accuracy assessment was carried out. The results obtained from the accuracy assessment are given in Table 9. When Table 9 is examined, there are no differences in accuracy levels at different grid spacing. Only the number of points exceeding 3σ is increasing. Selecting a grid spacing of 20 m will result in no height differences in details that are smaller than 20 m and will not be expressed in DTM, especially in creek cliffs and rocky regions.

Table 9. J51-a1 accuracy assessment of different grid spacing for edited DTMs

Grid Spacing (m)	# of points over 3σ (22 m)	Mean Error (m)	RMSE (± m) (68% C.I.)	Accuracy (± m) (90% C.I.)
5	1	-0.64	0.46	1.30
10	1	-0.67	0.48	1.36
15	3	-0.67	0.48	1.35
20	4	-0.67	0.53	1.41

4. RESULTS

When the accuracy assessments on the three different regions are examined, it can be seen that DTM, automatically generated from aerial photographs, has higher accuracy than other existing DTM data, namely DTED-2 and SRTM-1. The accuracy of the automatically generated DTMs, DTED-2 and SRTM-1 data available is given in Table 10 at 90% confidence interval.

Table 10. DTM accuracy assessment summary

Area	Height difference (m)	DTED-2 accuracy (± m)	SRTM-1 accuracy (± m)	DEM5m accuracy (± m)
L23-b3	800-1800	11.95	11.18	2.51
L30-b1	900-1000	3.63	2.93	1.38
J51-a1	1930-3300	8.03	8.20	1.30

When Table 10 is examined, DSM and DTM accuracies produced by automatic matching from aerial photos appear to be below ± 3 m when operator error and aerial photo orientation errors are summoned up. In areas with very flat, low vegetation coverage, accuracy is close to orientation of aerial photos.

Automatic DSM and DTM production from aerial photos takes about 40 minutes for a 1: 25,000 scale map sheet area, with a 4-core Xeon Dual processor workstation. For each map sheet area evaluated in the study, the time spent for editing from DSM to DTM and DTM to contours is given in Table 11.

Table 11. DTM accuracy assessment summary

Area	DSM to DTM (hours)	Editing automatic contours (hours)	Total time (hours)
L23-b3	43	19	62
L30-b1	6	8	14
J51-a1	13	17	30

When Table 11 is examined; it is seen that the most time spent on Usak L23-b3. The reasons for this are; the difference in altitude, the fact that 1/3 of the area is covered with dense forests, the presence of tree communities and bushes in the non-forested areas of area and the settlements. Aksaray L30-b1 map sheet has a height difference of about 100 m, with virtually no plant cover. Although the height differences are great in J51-a1 map sheet, the vegetation and the settlement are rare.

Are the whole country are taken into consideration; large town areas and fully forested areas where the DTM and the time of the final production can approach 10 days, besides the large flats and the plant cover is very rare; On average, it is estimated that DTM and contour production of a 1:25,000 scale map sheet area can last for five days.

5. CONCLUSION

In this study, the accuracy of the DEM produced by dense image matching compared with DTED-2 and SRTM-1 data in the same region of three different types of terrain and different topographic structures in Turkey with 1: 25,000 scale map sheet area. After the accuracy of automatically generated DEMs has been determined, the most appropriate DEM grid spacing has been determined according to the INSPIRE criteria.

When the existing countrywide DEM, namely DTED-2, is taken into consideration, newly proposed DEM5m improves the accuracy approximately five times. Also 5 m grid spacing means that DEM5m represent 36 times denser elevation points and better modelling of the terrain.

National mapping agencies in some other countries produce and present elevation data from a large number of elevation data producers (public and private sectors). These data are merged into a common pond. The elevation data requirements of all the institutions are met from the elevation warehouses. By only producing missing data are multiple efforts avoided for the same regions. In Turkey, especially public institutions produce large scale maps in urban areas and projects areas. In some limited areas they are getting DSM/DTM by laser scanning. If the data can be combined under the same roof, time and costs can be saved.

It is also important to determine the accuracy of the elevation data. For this purpose, geodetic points, leveling points within TUTGA and TUSAGA and the ground control points for aerial photography can be used. Every ground control point to be built by public institutions should be included in this control.

Last but not least, it is proposed that all efforts to produce elevation data should be integrated to generate a countrywide elevation database with different grid spacing and accuracies. But only the metadata of the elevation products should be supplied with central elevation database. By this central elevation database; repetitive efforts to produce elevation data can be avoided, time and resources can be saved.

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